MONITORING OF THE MOISTURE AND SALT LOAD IN RESTORATION PLASTERS IN ST.-BARBARA’S CHURCH IN CULEMBORG

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Abstract
St.-Barbara’s Church in Culemborg in the Netherlands has a history of moisture and salt damage to the plaster. In the past several restorations were performed, without a durable result. Finally, in 1997 test panels were applied in order to base the choice for new plastering on in practice proved durability. TNO Building and Construction Research used the church as a case study within the COMPASS project. The salt and moisture load in the walls and in the plaster of test panels in the church were determined. From these investigations, conclusions were drawn concerning the performance of different commercial restoration plasters.

1. Introduction
St.-Barbara’s Church in Culemborg is a case study within the COMPASS project. This project, funded by the European Commission, focuses on the compatibility of restoration plasters with salt loaded substrates. The main aim of the project is to provide restoration architects and authorities, involved in maintenance of the built cultural heritage, with clear guidelines for the choice of better compatible render and plaster mortars. From the case studies knowledge is derived on the type of plasters and renders used in practice, their performance in the field and the conditions under which failure occurs. This knowledge supports the research for clear guidelines for compatible application and also forms a basis for product development.

This article describes the case study of St.-Barbara’s Church, concerning it’s history, the applied materials, the damage, determination of the moisture and salt load and the interpretation of the investigation data. It gives some conclusions on the performance of mortars.

2. History of the church
St.-Barbara’s church in Culemborg (figure 1) is a Dutch Reformed church. Construction of the church started in the 14th century. Because of a fire in 1422 and different phases of expansion, construction took place until the 16th century. Between 1964 and 1968 several restorations were performed. From 1968 till now, no considerable interventions for maintenance have been undertaken. The existing plaster shows discoloration, salt efflorescence, crumbling, delamination and scaling and also peeling of the paint layer occurs.
Since approximately 1997 a restoration architect, a research institute and an institute for the conservation of monuments are involved in a project team working on a plan for restoration. The plan includes the assessment of the durability of test panels of different restoration mortars applied on-site. Assessment of the panels takes place by visual inspection and determination of moisture and salt load in the plaster. Frequency of the inspections by the project team of the church is unknown.

3. Restoration mortars

Over the past decades the building materials industry developed restoration plasters, especially to be applied on walls (masonry) containing high quantities of salt (and moisture). The two (main) ‘working’ principles of salt resistant mortars are the principle of salt transport and of salt accumulation [1].

A salt transporting mortar is an ‘open’ porous mortar, consisting of one layer. Moisture and salt transport take place to the surface, crystallisation of salts takes place on the surface. The finish should also allow the salts to crystallise at the surface without damaging the plaster, some maintenance to the paint is accepted.

A salt accumulating mortar accumulates salts in the render or plaster. The salts should not be transported to the surface. This system generally consists of more layers. The top layer has water repellent properties. The base layer is an ‘open’ layer with large pores. Water transport through the base layer is possible, through the top layer it is in principle only possible as vapour. Drying and crystallisation of salts are supposed to occur only in the base layer. The salts will not be transported through the top layer. This principle mainly originates from the German market. In Germany a kind of certification of this type of restoration mortar exists, based on a guideline [2] of WTA (Wissenschaftlich-Technische Arbeitsgemeinschaft für Bauwerkserhaltung und Denkmalpflege e.V.).
4. Test panels in the church

The test panels were applied in the church between September and December 1997, making use of different restoration plasters. One of the used systems is a salt transporting system, the other systems are salt accumulating systems. Different plasterers applied the panels, each taking care of one system.

The test panels are located on the northwest side and the southwest side of the church. On the northwest side five panels are applied next to each other on the north facade (panels 1N-5N). On the southwest side of the church, the panels are located on the west facade (panels 1W-3W) and the tower wall (panels 4T-5T). The west facade is nowadays partially an inner wall, adjoining the bath rooms. The locations of the test panels are indicated in figure 2.

Figure 2 – Location of the test panels (above north facade, below west facade and tower)

The following systems are used:
System 1, panel 1W (salt accumulating system):
- a bonding layer based on natural hydraulic lime,
- an undercoat layer impermeable to water, but vapour permeable,
- a water repellent, but vapour permeable, finishing layer.
- a paint (type unknown)
Thicknss of the system applied here was approximately 1.5 cm.

For unclear reasons the test panel on the west facade consists of other mortars, panel 1N (it is not clear what type (principle) of system this is):
- a bonding layer based on natural hydraulic lime,
- a trass lime mortar.
- a paint (type unknown)
Thickness of the system applied here was approximately 3 cm.

System 2, panel 2W, 2N (salt accumulating system):
- a bonding layer based on shell lime,
- a restoration mortar (WTA) based on Portland cement,
- a finishing layer based on shell lime,
- mineral paint (vapour permeable).
Thickness of the system applied here was approximately 3 cm.

System 3, panel 3W, 3N (salt transporting system):
- a salt transporting restoration mortar based on cement.
- mineral paint (vapour permeable).
Thickness of the system applied here was approximately 1.5 (W) and 3 (N) cm.

System 4, panel 4T, 4N (salt accumulating system):
- a bonding layer based on cement,
- a restoration mortar (WTA) based on cement,
- a finishing layer based on cement,
- silicone based paint.
Thickness of the system applied here was approximately 4.5 (T) and 3 (N) cm.

System 5, panel 5T, 5N (salt accumulating system):
- a bonding layer based on trass lime,
- a restoration mortar (WTA) based on trass lime,
- a finishing layer based on trass lime,
- silicate based paint.
Thickness of the system applied here was approximately 4.5 (T) and 3 (N) cm.

5. Investigation
TNO visited the church within the COMPASS project in December 2002 and May 2003. The visits included a visual inspection and sampling. By visual inspection the appearance of moisture and salt damage was evaluated. Samples were taken in order to determine the moisture and salt load in the walls of the church. Sampling was performed by powder drilling at different heights along the wall and at different depths in the wall. With the samples the salt and moisture distribution in the substrate and the test panels was determined.

6. Appearance of damage
By visual inspection the appearance of moisture and salt damage was evaluated. Panel 1W, a salt accumulating system, showed serious damage: scaling, crumbling and exfoliation of the plaster (see fig. 3). Damage occurred a short time after application. Panels 2W, 2N, 1N (salt accumulating systems) and 3N (salt transporting system) showed some superficial damage: blistering and peeling of the coating.
Figure 3 – Damage to test panel 1W

7. Moisture and salt distribution in the substrate

The following figures (4 to 6) give the average salt and moisture load in the substrate, for the 3 different locations of the test panels, the north facade, the west facade and the tower wall. The (hygroscopic) moisture content in the outer part of the substrate, the ‘surface’, and in the ‘substrate’, at a depth of approximately 10 cm in the substrate are given. The hygroscopic moisture content at 96% RH is used as an indication for the presence of salts [3], [4]. In the figures the continuous line gives the moisture content, the broken line the salt content.

Figure 4 – North façade: moisture and salt (hygroscopicity) content
The figures 4 to 6 show that the actual salt and moisture load diverges from place to place in the structure. It shows the occurrence of rising damp, in the north and west façade up to approximately 80 cm above floor level and in the tower up to at least 150 cm. The lowest moisture load is found at the west façade, the highest (up to 17%) at the tower. The hygroscopic moisture content is higher near the surface than in the depth. This indicates moisture and salt transport to the surface and plaster. The hygroscopic moisture content is highest at the west façade, lowest at the tower wall.

8. Salt load in the restoration plasters
Considering the principle of the salt accumulating or transporting restoration mortars, we can expect a certain salt profile over the plaster and substrate. Sampling the plaster and substrate in
different steps, for an accumulating system, we may expect a salt peak in the base layer of the plaster. For a transporting system, we may expect a salt peak at the surface of the plaster. The following figures show the moisture and salt profiles in the plaster and substrate at 100 cm above floor level. The continuous line gives the moisture content, the broken line the salt content (hygroscopicity). The vertical line indicates the location of the interface between plaster and substrate in the sample.

![Figure 7 – Moisture and salt load panel 4W](image)

The profile in figure 7 corresponds to the expectations of a salt accumulating system. This salt accumulating plaster seems to perform as intended. It does not show damage under high salt and moisture loads. In another case study in the COMPASS project a similar distribution was observed, showing no damage after 2 years.

![Figure 8 – Moisture and salt load panel 1W](image)
Figure 9 – Moisture and salt load panel 2W

The profiles in figure 8 and 9 do not correspond with the expectations of a salt accumulating plaster. System 1W showed a lot of damage (high salt load in the plaster), system 2W showed no damage. For system 2W it seems that the interface between plaster and substrate obstructs the salt transport to the plaster. This was also observed in another case study in the COMPASS project.

Figure 10 – Moisture and salt load panel 3W

The profile in figure 10 corresponds to the expectations of a salt transporting plaster. Superficial damage was observed on the coating, no salts were visible.

9. Impact of location

Figure 11 shows the salt load in a salt accumulating system on two different locations (2W, 2N) in 2002, at a height of 100 cm above floor level. The vertical line gives the location of the interface between plaster and substrate, for both panels at about 3 cm.
Figure 11 – Salt load in test panel 2N and 2W

On W a salt peak is present in the substrate, on N in the base layer of the plaster. At the north facade the plaster works according to the expectations of a salt accumulating system. At the west facade it does not; however no damage in the form of loss of adhesion or similar was present at the time of sampling.

10. Development in time

TNO determined the moisture and salt load of the substrate and of the test panels at two moments in time, in December 2002 and May 2003. For both a salt transporting and an accumulating plaster, the salt load in the plaster should increase during time. The figures 12 and 13 give the salt load of the transporting plaster (3N) and an accumulating plaster (2N) in 2002 and 2003, at a height of 100 cm above floor level. The marker to the left of the Y-axis gives the salt load in the plaster, the two other markers give the salt load in the substrate.
11. Discussion and conclusions

Generally a relation can be assumed between damage and high salt content in the plaster, as is shown in laboratory experiments [5], [6]. In the majority of the test panels, damage appeared quite limited for the time being, despite a sometimes high salt load. The age of the test panels was 5 years at the first and 5.5 years at the second inspection. The performance of plaster is related to both the salt and the moisture load. Figure 4-6 and 11 shows that the salt and moisture load strongly differ from place to place and depends on the
location in the building. The location will affect the performance of each single test panel. It is difficult to compare the performance of different plaster systems only by application on-site. For conclusions on the performance, comparison under identical conditions (under laboratory conditions) is necessary. The investigations on the test panels however allow to assess whether the applied plaster behave on site according to their working principle.

The profile in figure 7 corresponds to the expectations of a salt accumulating system. This salt accumulating plaster seems to perform as intended. It does not show damage under high salt and moisture loads. In another case study in the COMPASS project a similar distribution was observed, showing no damage after 2 years. Figure 9 shows that the absence of damage after a period of five years does not mean that a salt accumulating system performs as it should. The salts have accumulated in the substrate near the interface between plaster and substrate. In this case, damage, may occur later. This confirms a phenomenon observed in earlier research [5], [6]. The bond and the contact between plaster and substrate determine the possibility of moisture and salt transport from the substrate to the plaster and are important in order to prevent damage from occurring in the substrate. Apart from plaster properties, contact and bond very much depend on the execution.

Experience in the field showed that the type of coating on a salt transporting system may influence the type of superficial damage. Superficial damage was observed here as well. Another case study [7] showed that changes in relative humidity may cause increase in damage to a salt transporting plaster.

In general the 2nd sampling campaign showed a higher salt load in the plasters than the 1st. This increase however was still not high enough to cause damage and not representative enough to be sure that it is not caused by the difference in sampling location. Therefore a new sampling campaign is planned to take place on a short term, i.e. at seven years after application (two years after first sampling).

From the investigation in St.-Barbara’s Church in Culemborg as a case study in the COMPASS project, the following conclusions can be drawn:
- The moisture and salt load may vary strongly from place to place in a building.
- Location and execution affect the performance of a restoration plaster.
- For conclusions on the performance of different restoration plasters comparison under laboratory conditions is necessary.
- The absence of damage after a period of five years under a high salt load does not mean that a restoration plaster performs according to its working principle; salt distribution should be investigated.
- A period of half a year in between two measurement campaigns is too short to conclude on the development of the salt load in the plaster.
- The absence of damage after five years is not a guarantee for a long service life: once having reached a high salt load, damage may develop on a short term, as is shown by laboratory research.
- A sound comparison of the performance of different plaster systems can only be obtained on the basis of laboratory test under equal conditions. However the observations on test panels on site allow to include the influence of several factors, like differences in substrate and in salt and moisture content of that substrate as well as the influence of execution; this makes the test panels an excellent complementary part of the research.

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12. References


